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Call for a Census of Soil Invertebrates (CoSI)

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Abstact
A case is argued for urgent reappraisal of biodiversity of soils in order to mitigate their rapid global decline (MEA). A first step is to compile a 'stock inventory' of soil fauna thought to number around 210,000 species. Basic knowledge is yet wanting and even earthworms are poorly known despite being the major component as well as key environmental-engineers and vital links in all terrestrial food webs (including in waterways, hence their excellence yet trivial use as bait). That biodiversity of earthworms is disproportionately underappreciated is surprising as, with 10,000 already named and many more expected, they are no less species-rich than marine polychaetes, for example, that number ca. 8,000 valid taxa with 300+ wokers worldwide. A model for CoSI is the 10 yr, $1 billion global Census of Marine Life (CoML) that concluded with 250,000 total ocean taxa, but since 2 million species are already catalogued and estimates of diversity are of 10 million, this represents 12.5% of described species and just 2.5% of a probable total. Even claims that oceans occupy two thirds of the planet overlooks that land is hilly and the relative surface areas are perhaps 50:50. Socio-economic arguments flounder in context of 99% of the total worldwide human food supply produced on land, whereas oceans and other aquatic ecosystems provide a paltry 0.6% (FAO). Thus it seems timely and appropriate to advocate a sea change to firmly ground eco-taxonomic studies on our diminishing soils that support all life on Earth and, via runoff, provision or pollute the oceans too.
Keywords: biodiversity inventory, annelida, oligochaeta, extinction, taxonomy.

Introduction

"*The nation that destroys its soil destroys itself*" (T. Roosevelt, 1937).

Life on Earth springs from soil. Such a statement may seem trite, or obvious, yet no one could reasonably deny it. From this foundation we may assume that the manifest importance of our vital soil resource means that both its functioning and inventory is well understood scientifically and that great value ensures it is well protected and conserved. Yet such conditions are far from realized. Instead we find that our knowledge even of the most obvious and important component of the living soil, the earthworms or so-called "environmental-engineers", are particularly poorly known and, moreover, the importance of soils study seems to be derogated to a minor component of our concern or interest commanding a fraction of funding given to other research spheres.

Only 12% of the Earth is habitable and the share of terrestrial surface that is cultivated is just 24% with 5% supporting permanent crops upon which we all depend for our basic survival according to the UN's Millennium Ecosystem Assessment (MEA, 2005). Of this agricultural land, approximately 40% is seriously degraded. The 1991 UNEP funded Global Survey of Human-Induced Soil Degradation Report (GLASOD 1991) showed significant problems in virtually all parts of the world. The MEA, which despite its scope did not consider 'Soil Systems' separately, ranked land degradation among the world's greatest environmental challenges, claiming it risked destabilizing societies, endangering food security and increasing poverty.

Conversely, because the planet is perceived to be up to 70% ocean, the implication is that Marine Research deserves the bulk share of funding resources and research effort (see Blakemore, 2010). Superficially it may appear mostly water, but the sea is level while the Earth is obviously not flat - it is hilly with mean height ~840m amsl. When evened out, the relative surface areas exposed to sunlight are perhaps 50:50 Soil:Sea, as imagined in the NGA satellite and computer image (Fig. 1).

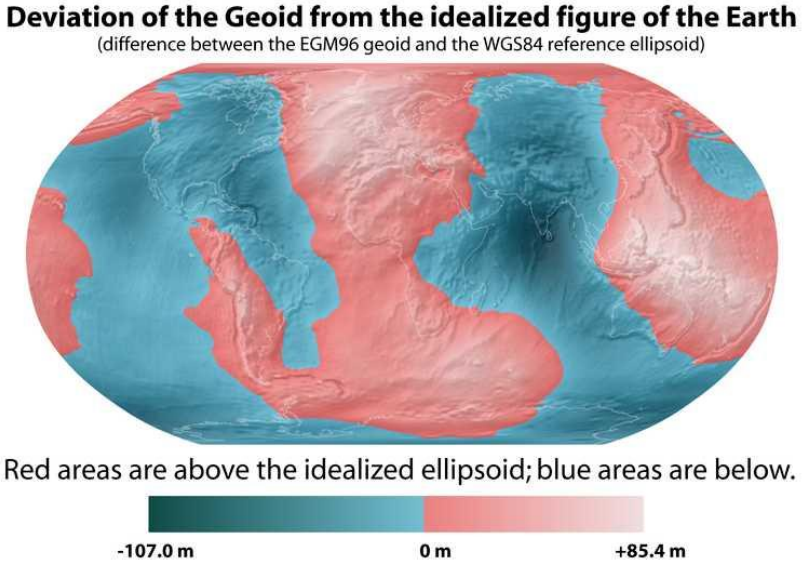
Deviation of the Geoid from the idealized figure of the Earth
(difference between the EGM96 geoid and the WGS84 reference ellipsoid)
Red areas are above the idealized ellipsoid; blue areas are below.
-107.0 m
0 m
+85.4 m

Fig. 1. Idealized Geoid (http://en.wikipedia.org/wiki/Geoid).

Conclusion of CoML

Nevertheless, priority was given to commission a 10 year **Census of Marine Life** (CoML) program sponsored by The Alfred P. Sloane Foundation to $700 million plus additional infrastucture and staff costs in order to map the biodiversity of the oceans. The scientific goal was to divulge what lives under the sea on the rationale that oceans cover most of the Earth's surface and are mostly uncharted with a socio-economic justification related primarily to fisheries management.

In its conclusion in October, 2010 the final report (CoML, 2010) stated "*It upped the estimate of known marine species from about 230,000 to nearly 250,000. Among the millions of specimens collected in both familiar and seldom-explored waters, the Census found more than 6,000 potentially new species and completed formal descriptions of more than 1,200 of them*." This seems to imply that on average each year 2,000 new records were added with 600 unknown to the 2,700 scientists employed. Another reckoning is that the investment needed to facilitate the formal description of 1,200 new species at a rate of 10 per month over the 10 years amounted to $580,000 each! At a time of rapid extinction (of species and taxonomists), such a cost and rate of progress is a model that requires modification improvements. [Incidentally, this figure of 1,200 spp is about the same number of earthworms described by the master Oligochaetologist, Dr Wilhelm Michaelsen (1860-1937) in a career spanning 53 years at Hamburg Museum].

The international Global Earth Observation System (GEOSS), that aims to provide comprehensive environmental analyses, accepted contributions from CoML, mainly in the areas of Climate, Ecosystem, Agriculture and Biodiversity (which is rather ironic since soils overwhelmingly determine these factors). Its major contributions were given as these three examples:

1. Fisheries Tracking.
2. Ecosystem and Habitat Documentation.
3. Marine Biodiversity Data Management and Exchange.

However attempts to justify marine research on the basis of socio-economic value of fisheries must surely flounder when viewed in context. The total 2006 fish haul and aquaculture combined approximated 144 million tonnes of which 110 million were for human consumption (from http://www.fao.org/fishery/sofia/en Oct., 2011). This less than global production of just poultry and eggs for the same period amounting to 150 million tons (http://www.fao.org/ Oct., 2011). Moreover, greater than 99% of the total worldwide human food supply is produced on land, whereas just 0.6% comes from oceans and other aquatic ecosystems combined according to FAO/AGL (2004).

Secondly, the ocean ecosystems are more uniform than soils because currents move sea organisms thus there is much intermingling, whereas sedentary groups such as earthworms are often highly endemic, even up to Family level, which is why they prove useful to confirm theories of continental drift (Wegener 1915, Michaelsen 1922).

Thirdly, this mixing by currents has consequences for ocean biodiversity and even CoML acknowledges (www.coml.org/census-framework) that only their coastal fringe is biodiverse: "*While the shelves comprise only 10 % of ocean areas, they contain most of the known marine biodiversity*". This due partly or wholly to runoff from the land that

provides the nutrients and, when poorly managed, causes the pollution. The vast, deep ocean may then be likened to a lonely desert that is mostly depauperate, just like the sky.

Soil Ecology Institutes Lacking Nationally and Internationally

Taking the GEOSS example slightly further because of their four main divisions of scientific research, on land or in the sea, air and space, we can readily see that the latter three of these fields obtain the bulk of the funding resources. Almost every nation hosts many national or international facilities for sea, air (atmosphere) and space-based research and often these are combined, yet for some unfathomable reason, there is scant consideration of the soil. Some examples of well known research facilities from amongst the 633 additional supporters of CoML projects are:

Atmosphere and Ocean Research Institute, University of Tokyo
Australian Institute of Marine Science (AIMS)
Japan Agency for Marine-Earth Science and Technology (JAMSTEC that works for "*the improvement of marine science*")
Marine Biological Laboratory (MBL) (Woods Hole)
New Zealand National Institute of Water and Atmospheric Research (NIWA)
National Oceanic and Atmospheric Administration (NOAA)
National Aeronautics and Space Administration (NASA)
Scripps Institution of Oceanography
Woods Hole Oceanographic Institution

It may be noted that several of institutes combine Atmosphere with Oceanography in their brief, **i.e. they study everything but the land beneath our feet**. In contrast NASA looks to the stars as just one representative of the myriad Astrological Institutions globally which are problematical when advancing astrophysical work is at the expense of progress closer to home: most stellar bodies will still occur in the heavens tomorrow, while the present human-mediated 6th massive extinction event (Wilson, 2005) means that many species will not. Each species is an intricate work of nature, irreplaceable beyond any work of art, and some will be lost before they have even been recorded, with no way of putting a price or value on this loss. Triage is required as not all science is equal, especially where time is a factor because of topsoil loss, imminent extinctions and irreplaceability of species.

Quentin Wheeler (2004, 2010), while advocating Taxonomic Triage, also asks "***What would NASA do?***" in the hypothetical scenario where a planet was found that, like our Earth, supported a wealth of life forms yet had only a tiny fraction catalogued. We can guess the answer. Thus the quote attributed to Leonardo Da Vinci, circa 1500's that "*We know more about the movement of celestial bodies than about the soil underfoot*" is even more poignant and inexplicable today due to this urgent crisis on Earth.

In stark contrast to the astronomical space funding and abysmal marine research, there is no single SOIL ECOLOGY INSTITUTE or organization offering an equivalence in study of down-to-earth Soil Ecology. I can find only one: the Helmholtz Zentrum Institut für Bodenökologie in Munich that seems to focus on microbial activity in soils. In the UK the Cranfield National Soil Resources Institute and The Macaulay in Scotland offer some ecological services and study "physical, chemical and biological processes" and "land use", respectively. India has an Institute of Soil Science, rather ironically, at Bhopal; and many universities and institutes have departments researching soils ad hoc

(e.g. the Soil Ecology Research Group at Yokohama National University) but most are seemingly modest and uncoordinated ventures by comparison to the other spheres.

Thus the contention remains there is no comparable Institute of Soil Ecology anywhere on Earth. When lamenting this at the IOTM-5 meeting in Switerzerland, I was informed that there was one, in Brazil, with 60 plus staff; however, on researching the facts, it appears just another agrichemical/GMO franchise cabal, with little or no biology/ecology component as, according to their website, Embrapa Solos Rio de Janeiro acts as: "*An international reference for Soil Science, this research center with 67 researches has an infrastructure for* ***chemical, physical and mineral laboratory analysis****, information system and geoprocessing*." (Website, Sept. 2011: http://www.embrapa.br/english/embrapa/unidades_de_pesquisa/cnps/).

Furthermore, to the best of my knowledge, neither does a single full-time curator of earthworm taxonomy remain at any institution anywhere in the world (the last to go perhaps was Dr Csaba Csuzdi at Hungarian National Museum). This is in contrast to legions of marine workers including many polychaete specialist employed around the world as their Polychaete Researchers Online websites (http://biocollections.org/pub/worms/pro/pro-new.html; annelida.net) boasts 300+ members and informs on biodiversity.

For the reasons presented here, the public under-funding of soil eco-taxonomic research on soil fauna in favor of marine or aquatic ventures, and especially exploration of space, is arguably an extravagant and unbalanced socio-economic and ecological decision.

Neglected soil organisms

Possible reasons for this lack of interest or support are that it is falsely assumed that all soil taxonomy has been completed, presumably because Darwin (1838, 1881) worked on earthworm for a period of 40 years, or, one supposes, on the relatively low diversity of previously glaciated northern climes where many earlier studies were conducted. Thus the UK has barely 80 earthworm species and continental USA totals just 200, while in contrast New Zealand and Australia are expected to yield between 1,000-2,000 species apiece (Blakemore, 2008). Another obstacle may be that soil ecology is often seen as an impediment to 'tidy' laboratory, glasshouse and even field experiments. Biology is naturally variable, unlike physico-chemical reactions which are entirely predictable and reproducible with few replicates (allowing for experimenter error or equipment failure) which is why small scale experiments are often conducted on sterilized soils devoid of life. For pots or mesocosms, even a single earthworm interloper would severely disrupt chemical, physical and mineral laboratory analyses and, ultimately, skew the plant responses (see Fig. 2).

Earthworms also suffer from the scale of observation from field surveys in which samples are unsuitable, say less than 50 mm diameter that work for mites, nematodes and other microfauna; whereas larger worms need quadrats of at least 100 mm thus slightly greater sampling effort. Identifications are also problematical when our knowledge of the biodiversity is so poor. Often the smaller species are overlooked or classed as unidentifiable immatures, while even larger species may well be new to science or new records for a region (Blakemore, 2008). There are few such comprehensive guide books and resources to current taxonomic identification of any but the most common of species

which forced the student to make a choice between one wrong answer or another wrong answer.

Report from such inadequate surveys seriously underestimate both earthworm abundance and diversity, whereas personal experience shows that these can both be high numbering in the dozens of species from just a single site (Blakemore 2008, cf. Lee 1985). Thus arguments firstly that the soil is well surveyed and the taxonomy well sorted out so that there are usually only two or three 'common' species on any farm site anywhere in the world requires debunking.

Another problem with earthworm funding is that whereas it is relatively simple to justify a project based on some economic loss, for example an insect that devours part of a crop, such economics are much more difficult for primary producers and detritivours that recycle the nutrients in the soil thus producing the initial productivity allowing the crop to sustain predation. Answering questions such as what would be the price if earthworms or pollinating bees were lost, some equivalent benefit rates for ecosystem services have been attempted. Pimental *et al*. (1997) costed formation of topsoil at US$25-50 billion each year in the USA alone; and the minimum benefit of natural decomposer recycling at more than US$760 billion per year worldwide.

Further economics are provided on the ALG/FAO (2004) **Soil Biodiversity Portal** (http://www.fao.org/ag/AGL/agll/soilbiod/consetxt.stm) that itself seems to have been underfunded and to have languished for the few years, as a case in point. In a useful summary, however, they quote Pimental *et al.* (2005) showing that a diverse soil biota facilitate soil formation and improve it for crop production, with the example of earthworms bringing between 10 and 500 tons/ha/yr of soil to the surface, contributing to redistribution of nutrients, soil aeration and drainage, facilitating topsoil formation and thereby enhancing plant productivity, as is dramatically demonstrated in Figure 2.

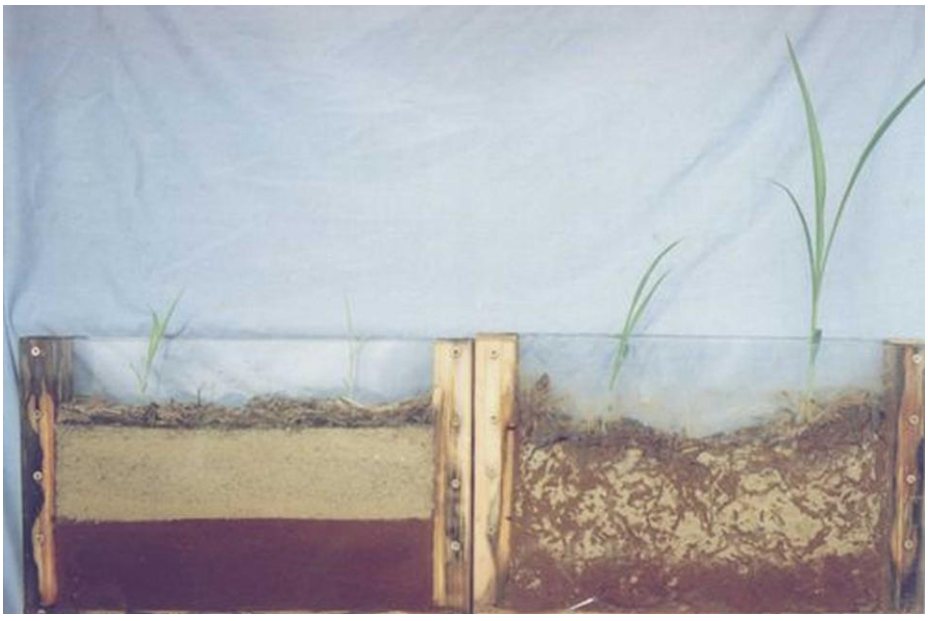

Fig. 2. **Fig. 0.0.** Soil effects & plant (*Sorghum bicolor*) growth in two weeks without (lhs) or with earthworms (rhs + four *Pontoscolex corethrurus*) introduced ca. 12 wks before (figure courtesy of Dr Les Robertson of BSES Tully, Qld).

Conclusion

When a house is on fire, it seems both illogical and ill-advised to go 'star-gazing' or to only attempt to rescue the pet goldfish. Yet that is what we now seem to be doing.

This CoSI proposal may upset some interests but not when rationally evaluated for the most cost efficient and ecological research benefit for all. There is need for Science to disinterestedly redress imbalances and to seek answers on the most crucial questions raised, and at least it should stimulate a debate which seems at present to be lacking. As CoML is praised for its achievements or we wonder at the latest cosmological find, the soil remains as the last great unexplored megadiverse habitat with a handful of topsoil containing tens of thousands of species, most totally unknown and undescribed. Thus it may well be called the "*poor-man's rainforest*" and the journal Science, realizing that our knowledge is so scant, produced a special 2004 issue entitled: "*Soils – The Final Frontier*" (http://www.sciencemag.org/content/vol304/issue5677/#special-issue).

A proposed solution, for earthworms at least, is rapid eco-taxonomic field expeditions (with modest equipment - basically a spade and GPS) combined with sweeps of museum shelves to 'harvest' small tissue samples from types (lectotypes, holotypes and neotypes), however briefly or badly the species were described or specimen preserved. The unique species name may then be permanently anchored via its type to a DNA 'barcode' for all to freely use thereafter (Blakemore *et al*., 2010; ICZN, 1999; IBOL, 2011). Another model is the "*Plant-Bug Systematic Catalogue*" database that obtained publishers' permission to freely reproduce and redistribute publications on their taxa (see http://research.amnh.org/pbi/catalog/index.php). Internet services would aim to avoid the current Genbank practice of sequencing voucher specimens and delegating correct identification for someone else to work out later which is both unrealistic and unproductive.

Finally, total soil faunal biomass of a typically fertile soil (with the earthworms making up the bulk but not counting microbes, bacteria, algae or fungi) is shown in the following table (Table 1) with soil fauna populations typical of temperate regions (modified from Gobat *et al.* 2004, Table 2.11). Total species (known and unknown) for the various common soil faunal groups are also estimated, but the compiled data in Table 1 may be compared to FAO/AGL, (2004 http://www.fao.org/ag/agl/agll/soilbiod/soilbtxt.stm) where their biodiversity total is approximately half, once again demonstrating our lack of confident consensus on true biodiversity of our precious soils.

Table 1. Abundance and biodiversity estimates for common soil Invertebrates [from Brusaard *et al*. 1997; Wall & Moore 1999, Chapman 2009; Turbe *et al*. 2010: Tab. 1.; Blakemore, 2012 and Wikispecies (e.g. http://en.wikipedia.org/wiki/Wikispecies) sources and pers. obs.]. Note: all species have many unique symbionts/parasites too.

Soil Invertebrate Group	**Individuals m^{-2} (approx.)**	**Biomass g m^{-2}**	**Known species**	**% Known**
Bacteria and Archaea	10^{12}	20-500*	3,200	<<1%?
Fungi	(500+ km)	20-500*	80,000	0.5%
Protozoa	10^{10}	6-30	1,500	8%
Nematoda	10^{6}	1-30	25,000	"1.3%"
Lobopodia (Onychophora, Tardigrada)			**~1,200**	**<<50%**
Lobopodia (Onychophora,)	*?*	*?*	*<200*	*50%*
Lobopodia (Tardigrada)			*~1,000*	*?*
Acari (mites)	10^{4}	0.2-4	45,200	4%
Hexapoda (totals)	**10^{4}**	**0.2-4**	**~9,000**	**17%**
Hexapoda (Collembola)	*Up to 100,000*		*6,500*	
Hexapoda (Diplura)			*800*	
Hexapoda (Protrura coneheads)			*731*	
Soil Insecta and their larvae	50-500	4.5	55,000+?	20%?
Myriapoda (centi-, millipedes)	**100-1100**	**1.5-22.5**	**18,000**	**20%**
Myriapoda (Symphyla)			*160*	
Pauropoda (Myriapoda relative)			*500*	
Isopoda (slaters, woodlice, etc.)	Up to 1800	<4	5,000	?
Isoptera (Termites)	Colonies	?	2,600	60%?
Blattodea (Cockroaches)	?	?	4,500	?
Ants (Hymenoptera : Formicidae)	Colonies	?	13,000	50%
Molluscs (Soil Gastropods)	?	?	24,000	40%?
Terrestrial Turbellaria (Planarians)	?	?	830+	?
Terrestrial Polychaeta	?	?	?	?
Oligochaeta (Mega-, Microdriles)	**50-500**	**20-500**	**10,000**	**20%?**
Microdriles (Enchytraeidae)			*~700*	*?*
Microdriles (Etc.)	*?*	*?*	*?*	*?*
Megadriles (true earthworms)	*50-500*	*20-500**	*6,000*	*<20%?***
Total species (approx.)			**300,000**	**?**

* Sub-surface biomass estimates of some organisms (even excluding plant roots and tubers) often exceed above-ground biomass. **[NOTE: Author's proportional unknowns give total >30,000 Megadrile species].

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